3 THE KILN DRYING OF PREVIOUSLY AIR-DRIED VIROLA (DIALYANTHERA SPP.)

By

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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

In Cooperation with the University of Wisconsin

THE KILN DRYING OF PREVIOUSLY AIR-DRIED VIROLA (DIALYANTHERA SPP.)

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Abstract

Brownheart portions of Colombian virola (*Dialyanthera* spp.) used for core stock sometimes collapse and produce wavy-surfaced hot-pressed panels. To determine whether air-dried wood of this type could be kiln dried successfully to a uniform moisture content without collapse and honeycomb, three kiln runs were made. The ultimate goal was to avoid distortion during hot pressing by precision drying the material.

This research indicated that, by using a mild schedule and by assuming an artificially high kiln sample moisture content for pieces with wet zones, such stock can be kiln dried without collapse, excessive shrinkage, or honeycomb to a uniform moisture content, free of stress. The best results were obtained using a modified U.S. Forest Products Laboratory hardwood kiln schedule T3-C3. The elapsed time was 6-3/4 days, including equalizing and conditioning. Since the material was limited, the results should not be regarded as final and conclusive.

[1]Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Introduction

This report covers research[2] on the kiln drying of the so-called virola from southwestern Colombia. The lumber, specially selected for its brown-streak material, was furnished by the Far Islands Timber Company, Los Angeles, Calif.,[3] with the cooperation of the Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif. It was shipped by motor freight from Morehead City, N.C., arriving at the Laboratory May 17, 1959.

Species

Although shipped under the name virola, examination of the wood with a hand lens[4] indicated it was a species of Dialyanthera, of the Nutmeg Family (Myristicaceae). It is known in the Pacific Coast area of Colombia as "cuangare." In the absence of corresponding herbarium material (leaves, flowers, and/or fruit), it is impossible to identify the precise species. More than one species of Dialyanthera may have been represented in this shipment.

Although the name "virola" is now frequently applied to this wood in the trade, it is somewhat a misnomer, since Virola is the botanical name for another distinct genus of the same plant family, represented by

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[2] Under the supervision of Mr. J. M. McMillen, Technologist.

[3] Correspondence, Far Island Timber Company, May 11 and June 2, 1959.

[4] B. Francis Kukachka, Division of Timber Growth and Utilization Relations.

Subsequent hot-pressing trials with some of the stock produced wavy panels, so the ultimate goal was not attained. Brown-streaked virola should not be used for hot-press panel core stock.

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several species in northern South America. The use of "virola" for a species of Dialyanthera is like calling hickory a walnut, since both belong to the same family. In this respect, therefore, preference should be given to the use of the local name "cuangare," rather than "virola."

Source

This material originated in the Tumaco region, on the Pacific Coast of southwestern Colombia.[3] This is a low-lying, humid area with a high annual precipitation, and the vegetation is of the dense rain or evergreen-forest type. As in other tropical forests, the species is scattered and mixed with many other types of trees. An aerial picture of the mill indicates that the logs are stored on tidal flats, subject to alternate wetting and drying.

Problem

This wood is now being used on an increasing scale for core stock. In some shipments, a type of wood known as brown heart has been present in a portion of the stock. When cores made by edge-gluing such brown-heart stock are hot-pressed with crossbands and face plys into conventional plywood panels, wavy panels have sometimes resulted. Also, collapse often occurs in the brown streaks. Honeycombing frequently accompanies the collapse.

As received, the experimental material had some dark streaks on the surface, and freshly cut cross sections showed fairly large areas of very wet wood. The problem in this experiment was to see if the streaky

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As received, the experimental material had some dark streaks on the surface, and freshly cut cross sections showed fairly large areas of very wet wood. The problem in this experiment was to see if the streaky

and wet material could be easily kiln dried to a uniform moisture content without collapsing or honeycombing in the process.

Subsequent to completion of the drying, it was the job of another division of the Laboratory to determine if the carefully dried stock could be satisfactorily hot-pressed into panels.

Scope

To determine a satisfactory kiln drying procedure, the material was divided into three batches for (1) an exploratory kiln run using a schedule recommended for mahogany, (2) a pilot test with a schedule modified on the basis of results from run 1, and (3) a kiln run using a time schedule. The presence of interior wet streaks required development of an artificial method of assigning kiln sample moisture content values. The general plan was to dry all the wood to an average of 8 percent moisture content, with 7 percent as minimum and 9 percent as maximum.

The schedules, drying procedures, and analyses of the results for the drying study are given separately by kiln runs. A brief discussion of the study then follows.

Although not a part of this experiment, the results of the hot-pressing of solid-core plywood from the material are discussed to round out the consideration of the suitability of the brown-streak stock for such a use.

Material and General Procedure

Material

The shipment consisted of about 100 board feet of 1- by 3- to 8-inch by 4- to 6-foot rough lumber of average quality. It had been previously air-dried in Colombia. Immediately upon arrival at the Laboratory the material was examined. Some of the boards had dark streaks on the outside as well as in the interior. The interior dark zones did not necessarily coincide with the surface streaks nor with the interior zones of very high moisture. By mere superficial examination it could not be readily determined whether these irregular darker zones were indicative of a higher moisture concentration, caused by heartrot (decay) fungi, or a chemical discoloration. Some consideration was also given that these streaks formed part of the heartwood, although usually in the woods of this group the line of demarcation between the heartwood and sapwood is not well defined. Furthermore, there is no information at what stage these streaks appear--whether in the standing tree, in the logs near the stump, during transport between the forest and the mill, as the result of improper or insufficient air drying, or during storing and shipment of the air-dried lumber.

Subsequent to the start of the kiln drying, some stained "brownheart" specimens were microscopically examined[5] to determine whether or not fungi were associated with the discoloration. In all brown discolored areas, including one stained sapwood area as well as the stained heartwood, fungus

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[5] Joseph W. Clark, Pathologist, Division of Wood Preservation.

hyphae were present and abundant. The observed hyphae appeared to be those of decay fungi predominantly rather than stain fungi, but no cultures for positive determinations were made.

Specific Gravity

The specific gravity was determined[4] on 10 samples cut soon after arrival of the material. On the basis of ovendry weight and ovendry volume, specific gravity ranged from 0.36 to 0.41, with an average of 0.39. Specific gravity of 31 previous samples of this wood, on the same basis, also averaged 0.39.

Kiln Samples and Moisture Sections

Ten boards that appeared to be the wettest and with dark streaks prevalent were selected and cut to furnish two equal sets of kiln samples about 23 inches long--one-half marked "A" and the other half "B." At this stage, also, a series of moisture sections, 1 inch thick sawn crosswise through the board, were cut. Three sections were obtained from the middle of each board; one to determine the specific gravity; a second marked "1a middle," "2a middle," etc., to determine the average moisture content; a third distribution section cut to provide a small zone which appeared to be the wettest as well as two dry end zones. Additional average moisture content sections were cut about 10 inches from each end of the "A" and "B" halves, marked "1a end," "2a end," etc., and "1b end," "2b end," etc.

The kiln samples were end-coated with a mixture of aluminum powder and phenolic resin varnish and weighed. The kiln samples and about one-third

of the unsampled material, marked "A," were immediately started in Run 1. The "B" samples and most of the remainder of the shipment were stored in a cold room at 35° F. and 82 percent relative humidity. In this room they were covered with a damp cloth.

Moisture Content Determination

All the moisture sections, including the wet and dry zones of the distribution sections, were weighed immediately on being cut. They were ovendried for 24 hours, after which period they were reweighed to determine their moisture content. In view of the fact that four moisture sections were taken from each board and one section was subdivided into wet and dry zones, there were five moisture-content values. The results applicable to the "A" samples are shown in table 1. For the moisture distribution sections, an unweighted average of the wet- and dry-zone moisture percentages for each sample is shown.

For each sample it was necessary to select one representative moisture value. In most cases this was either the moisture content of the middle section or the average of the dry and wet zones, whichever was higher. The arbitrarily selected high moisture content was then used to determine the calculated ovendry weight for the kiln sample. This weight, in turn, was used to calculate the moisture content of the sample during the first part of the drying run.

It should be indicated that, of the moisture sections at the initial stage, the wettest zone had a moisture content of 31 percent, while the driest section was 17.4 percent, indicating a wide range of moisture content

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For each sample it was necessary to select one representative moisture value. In most cases this was either the moisture content of the middle section or the average of the dry and wet zones, whichever was higher. The arbitrarily selected high moisture content was then used to calculate the calculated ovendry weight for the kiln sample. This weight, in turn, was used to calculate the moisture content of the sample during the first part of the drying run.

It should be indicated that, of the moisture sections of the kiln study, the wettest one had a moisture content of 91 percent, while the driest section was 17.6 percent, indicating a wide range of moisture content

and nonuniform air drying. On the basis of the arbitrary moisture content values used, the moisture content of the kiln samples in run 1 ranged from 25.0 to 64 percent.

Kiln Equipment and Piling Method

The three runs were carried out in a small experimental unit. It is equipped with two reversible fans and automatic control of vents and both dry- and wet-bulb temperatures. The load width was 4 feet. In the three kiln runs, the material was flat piled, lengthwise of the kiln, on 3/4- by 1-1/4-inch stickers. Sticker spacing ranged from 16 to 24 inches. Canvas baffles were dropped from the fan floor to the top of the load to prevent bypassing of any circulating air.

Run 1

Kiln Schedule

Taking into consideration the specific gravity of the species (average 0.39), its general appearance, and the reported susceptibility to collapse and honeycombing near the "brownheart," a mild drying schedule was indicated for the initial run. From "Schedules for the Kiln Drying of Wood," Forest Products Laboratory Report No. 1791, the basic mahogany schedule T6-C4 was selected and modified as follows:

Moisture content	Temperature: Dry-bulb	Temperature: Wet-bulb depression	Temperature: Wet-bulb	Relative humidity	Equilibrium moisture content
Percent	°F.	°F.	°F.	Percent	Percent
Green - 35	120	7	113	80	14.1
35 - 31	120	10	110	72	12.1
31 - 28	120	15	105	60	9.7
28 - 24	130	25	105	43	6.8
24 - 20	140	40	100	25	4.1
20 - 15	150	50	100	18	2.9
15 - final[1]	180	50	130	26	3.3
Equalizing[2]	180	35	145	41	3.0
Conditioning	180	8	172	83	12.2

[1]Driest sample, 5 percent.

[2]Continued until 3 wettest samples averaged about 6 percent.

Drying Procedure

Immediately before commencing Run 1, kiln samples marked "A" were reweighed, and it was determined that the moisture content values of these now ranged from 25.8 to 58.5 percent.

The run started at 2 p.m., May 19, 1959, with an initial dry-bulb temperature of 120° F. and a wet-bulb depression of 7° F. Changes in kiln conditions were generally made on the basis of the average moisture content of the three wettest samples using values derived from the arbitrarily high initial values. As drying progressed, it was considered desirable to further modify the drying schedule by estimating beforehand a drying curve

for the wettest zone in the wettest kiln sample. The changes in the relative humidity then were delayed until this zone was no more than 10 percent above the moisture content value at which the C4 wet-bulb depression schedule changes would be made. Also by arbitrarily selecting the highest moisture value of the several moisture sections, as outlined above, the time for applying high kiln temperatures which might cause collapse or honeycomb of the wet zones was delayed.

Since the average moisture content of the three wettest samples had dropped from 54 percent at the beginning of the run to 39.3 percent after 24 hours of drying, it was decided at 5 p.m., May 20, to make the first change in wet-bulb depression (from 7° to 10°). At 2 p.m., May 21, it was determined that the average moisture content of the three wettest kiln samples had been reduced to 31 percent. Consequently, a change in the wet-bulb depression was made at 4 p.m. on that day, going to 15° F. Two kiln changes were made during the third day.

After 3 days, 23 hours of drying, the moisture content of the three wettest samples averaged 19 percent. Intermediate moisture content determinations (U.S. Forest Products Laboratory Report 1607) were made, and it was evident that the wet zones had disappeared completely. Equalizing was begun, therefore, at 1:15 p.m., May 23, setting the dry-bulb temperature at 150° F., with a depression of 35° F. This was continued for almost 27 hours, until 4 p.m., May 24, when conditioning commenced. For this, conditions were set at 180° - 170° F. and continued for 16-3/4 hours, until 8:45 a.m., May 25--a total run of 5 days, 19 hours, including the period for equalizing and conditioning.

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Since the average moisture content of the three wettest samples had dropped from 34 percent at the beginning of the run to 29.4 percent after 24 hours of drying, it was decided at 3 p.m., May 20, to make the first change in wet-bulb depression (from 7° to 10°). At 2 p.m., May 21, it was determined that the average moisture content of the three wettest kiln samples had been reduced to 21 percent. Consequently, a change in the wet-bulb depression was made at 4 p.m. on that day, going to 15° F. The kiln changes were made during the third day.

After 3 days, 23 hours of drying, the moisture content of the three wettest samples averaged 15 percent. Intermediate moisture content determinations (U.S. Forest Products Laboratory Report 1657) were made, and it was evident that the wet zones had disappeared completely. Equalizing was begun, therefore, at 1:15 p.m., May 23, setting the dry-bulb temperature at 150° F., with a depression of 15° F. This was continued for about 27 hours, until 4 p.m., May 24, when conditioning commenced. For this, conditions were set at 180° -- 170° F. and continued for 16-1/2 hours, until 8:30 a.m., May 25 -- a total run of 5 days, 18 hours, including the period for equalizing and conditioning.

At the completion of the run, the kiln door was left slightly ajar and the vents open during the cooling period.

Moisture content values of the kiln samples, back to the beginning of the run, were recalculated on the basis of the intermediate moisture content results. Using the recalculated values, the actual drying conditions on Run 1 were as follows:

Moisture content at start of step	Temperature			Relative humidity	Equilibrium moisture content	Time
	Dry-bulb	Wet-bulb depression	Wet-bulb			
Percent	°F.	°F.	°F.	Percent	Percent	Hr.
50.8	120	7	113	80	14.1	[1]8
35.3	120	10	110	72	12.1	[1]27
24.9	120	15	105	60	9.7	[1]50
18.7	130	25	105	43	6.8	[1]66.5
15.7	140	40	100	25	4.1	[1]73
8.9	139	44	95	30	3.6	[1]95.2
Equalizing	150	35	115	34	5.0	26.8
Conditioning	180	10	170	79	11.1	16.8
Total Time						138.8

[1] Time elapsed in drying (per period otherwise).

Figure 1 shows the temperature, relative humidity, and the average moisture content of the three wettest samples, recalculated basis, during the run.

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Moisture content at start of step	Temperature: Dry-bulb	Temperature: Wet-bulb depression	Temperature: Wet-bulb	Relative humidity	Equilibrium moisture content	Time
Percent	°F.	°F.	°F.	Percent	Percent	Hr.
[illegible]	120	7	113	80	14.1	[1]4
34.0	120	10	110	72	12.1	[1]27
24.8	120	15	105	60	9.7	[1]50
18.2	130	25	105	42	6.2	[1]66.5
13.7	140	40	100	25	4.1	[1]73
4.9	130	35	95	30	3.6	[1]95.2
Equalizing	130	15	115	34	5.0	26.8
Conditioning	180	10	170	78	11.1	16.4
Total time						133.8

[1] Time elapsed in drying [illegible].

Figure 1 shows the temperatures, relative humidity, and the average moisture content of the [illegible], recalculated basis, during the run.

Analysis of Run 1

The moisture content values of the cross sections--average at mid-length and those separated by visual examination into dry and wet zones--are shown in table 1. From this it will be seen that in the middle sections the range extended from 24 percent, the driest, to 60 percent, the wettest. The average for all sections was 38.2 percent. In the dry zones the range was from 23.8 to 34.8 percent, and the average was 26.2 percent. These values compared with a high of 81 percent in the wettest wet zone and an average of all wet zones of 52.5 percent.

In table 2 a comparison is given between the arbitrary initial moisture content values assigned to each kiln sample, as cited in table 1, and that established by recalculation on the basis of the moisture content of the intermediate sections cut after 4 days of drying. This shows that the actual average moisture content values generally were lower than the arbitrarily used values. The danger of honeycombing and collapse would be greatest when wet zones were above 30 percent moisture content. Accepted kiln schedules, however, make use of average values which allow for normal differences between the dry shell and a wetter core. Thus, the use of arbitrary values appears justified to protect the stock during the first part of drying, but intermediate moisture content determinations would have been justified at the end of 2-1/2 to 3 days, or as soon as a test cross section showed no visibly wet spot.

The moisture content of the kiln samples before and after drying, equalizing, and conditioning is indicated in table 3. The average moisture

content for all the samples after conditioning was 8.4 percent, with a range for the 19 sections from 7.8 percent for the driest to 8.8 percent for the wettest. This was well within the objective, to obtain an overall average of 8 percent within a marginal range of ±1 percent.

Final test sections for the determination of moisture distribution in shell and core, average moisture content, and residual stress were cut. The results are shown in table 4. While there were individual differences, the final moisture content sections showed the driest was 8.2 percent, the wettest was 8.8 percent, and the average for all sections was 8.3 percent, a close check with the samples. The shells ranged from 7.6 to 8.8 percent, with an average of 8.3 percent; while the cores had 7.9 percent for the driest, 9.2 percent for the wettest, and 8.6 percent as the average.

One kiln sample, 6-A, showed slight surface checking on the second day of run, but these checks had closed up 3 days later. Another sample, 1-A, had 24 inches of surface checks, which appeared on the fourth day of drying. A third sample, 9-A, had 23 inches of surface checks in the brown streak on the fourth day. Some slight collapse appeared in sample 3-A on the third day, although this may have been present earlier. One sample had honeycomb when the stock arrived, but kiln drying did not aggravate its condition. The wet zones completely disappeared before equalizing. All samples were free of collapse and stress 48 hours after completion of the run.

content of all the samples after conditioning was 6.4 percent, with a range for the 10 [illegible] percent for the driest to 8.[illegible] percent for the [illegible]. [illegible]

[illegible]

[illegible] the average for all sections was 6.3 percent, [illegible] The shells ranged from 7.6 to 8.8 percent, [illegible]

[illegible]

the run.

Run 2

In the second run, 14 kiln samples were used. These were composed of the original 10 halves, marked "B," and 4 additional specimens selected at the beginning of Run 2 for their apparent dark, wet streaks. Several longer boards completed the charge. The kiln samples were end-coated with a roofing asphalt preparation and reweighed before placing in the charge. In an effort to overcome the surface checking observed in the exploratory run, a milder schedule was used.

The method of assigning arbitrary moisture content values to the kiln samples was essentially the same as in Run 1. Immediately on arrival at the Laboratory, the moisture content of the 10 "B" samples ranged from 23.8 to 60 percent, with the average of the three wettest being 56.8. The additional four kiln samples, cut and weighed immediately before Run 2 commenced, had 20.5 percent moisture content for the driest and 46.8 percent for the wettest, with the average of the two wettest being 34.2 percent.

Kiln Schedule

In Run 2 a modified T5-C3 schedule was used, as follows:

Moisture content	Temperature			Relative humidity	Equilibrium moisture content
	Dry-bulb	Wet-bulb depression	Wet-bulb		
Percent	°F.	°F.	°F.	Percent	Percent
Green - 35	120	5	115	85	16.2
35 - 31	120	7	113	80	14.1
31 - 27	120	10	110	72	12.1
27 - 24	130	15	115	62	9.7
24 - 20	140	20	120	54	8.0
20 - 15	150	25	125	44	6.9
15 - Final	160	50	110	21	3.2
Conditioning	170	8	162	82	12.4

Drying Procedure

The plan was to make intermediate moisture content determinations when the three wettest samples had about 24 percent moisture content. Drying could be accelerated if the wet zones had disappeared.

This run commenced at 2 p.m., May 29, with 120° F. dry-bulb and 115° F. wet-bulb temperature. These initial conditions were held for 48 hours. The controlling moisture content, on the basis of the arbitrarily high initial values, was 54.6 percent at the start. This had dropped to 33.8 percent average after 2 days of drying. Consequently, an adjustment was made in conditions; the wet-bulb depression was increased to 7° F. Eighteen hours later, at 8 a.m., June 1, the moisture content of the three wettest samples had dropped to 26.5 percent.

The wet-bulb depression was accordingly increased to 10° F. The dry-bulb temperature was still held at 120°F.

Intermediate moisture content sections were cut during the third day, when the average moisture content of the three wettest samples showed 26.5 percent. The moisture content for the wettest ovendried sections was 22.2 percent. The dry-bulb temperature was therefore increased to 130°F. The depression was changed to 15° F. After 4 days of drying, the moisture content of the three wettest samples was 14 percent. Conditions were then adjusted to 150° to 125° F. The charge was subjected to these conditions for 17 hours before stepping up to 160° F. and a wet-bulb depression of 50° F. for a period of 24 hours. At the end of that period the average moisture content of the three wettest samples was 7.4 percent. On the basis of this, it was not considered necessary to equalize. Conditioning started at 8:30 a.m., June 4, at 170° to 152° F. and continued for 24 hours.

The total elapsed time involved in this run, including conditioning, was 6 days, 12-1/2 hours (see Fig. 2).

Analysis of Run

The procedure adopted in determining the moisture distribution in the kiln samples at the time of cutting intermediate moisture sections was essentially the same as that at the beginning of Run 1. However, in addition to the sections taken for average moisture content and dry and wet zones determined by visual examination, another section was cut for dark-colored zones within or adjacent to the brown heart and light-colored zones. The object of this latter test was to determine whether the moisture content of the dark streaks approximated that of the wettest zones.

The wet-bulb depression was accordingly increased to [illegible]° F. The dry-bulb temperature was still held at [illegible]°F.

Intermediate moisture content sections were cut during the [illegible] day, when the average moisture content of the three outside samples showed [illegible] percent. The moisture content for the [illegible] sections was [illegible] percent. The dry-bulb temperature was therefore increased to [illegible]°F. The depression was changed to [illegible]° F. After [illegible] days of drying, the moisture content of the three outside samples was [illegible] percent. Conditions were then adjusted to [illegible]° to [illegible]° F. The charge was subjected to these conditions for [illegible] hours before stepping up to [illegible]° F. and a wet-bulb depression of [illegible]°F. for a period of [illegible] hours. At the end of this period the average moisture content of the three outside samples was [illegible] percent. On the basis of this, it was not considered necessary to equalize. Conditioning started at [illegible] a.m., June [illegible], at [illegible]° - [illegible]° F. and continued for [illegible] hours.

The total elapsed time involved in this run, including conditioning, was [illegible] days, [illegible] hours (see Fig. [illegible]).

Analysis of Run

The procedure adopted in determining the moisture distribution in the test samples at the time of cutting intermediate moisture sections was essentially the same as that at the beginning of the [illegible]. In addition to the sections taken for average moisture content and dry and wet zones determined by visual examination, another section was cut for fast-colored zones within or adjacent to the brown heart and light-colored zones. The object of this latter test was to determine whether the moisture content of the dark streaks approximated that of the original zones.

The results are given in table 5. The dry zones and the light-colored zones agreed very well in moisture content at this stage of drying. There was less general agreement between moisture values of wet zones and dark zones, but in six cases the dark zones were as wet as or wetter than the selected wet or damp zones.

The average moisture content values at the intermediate determinations were used to recalculate the starting moisture content of the kiln samples. A comparison of the starting moisture content based on the arbitrary initial moisture content values with the recalculated values is shown in table 6. This again shows that the actual average moisture content values were generally lower than those arbitrarily assigned, but the same comment as in Run 1 holds. The respective moisture content values of the 14 kiln samples at the various stages of Run 2 are also indicated in table 6.

The final moisture content and stress in sections from the kiln samples were cut the afternoon of June 5. The results are shown in table 7.

This kiln run took longer and gave stock at a moisture content higher than that of Run 1 because of the milder schedule. Again the results were that there was no collapse and casehardening was fully relieved, but there was a small amount of opening of checks. This schedule is more satisfactory, however, than the one used in Run 1 in respect to drying defects. Perhaps, if no surface checking had occurred during air drying, there would have been no kiln-drying defects. If the final drying step had been lengthened 12 hours and the conditioning period decreased to 18 hours, a lower final moisture content could have been achieved.

Run 3

Kiln Schedule

For the final run a still milder schedule, a modified T3-C3 schedule was used. It was, however, operated on a time basis. The charge was composed of six kiln samples, the remainders of boards 11, 13, and 14 from Run 2 and three other pieces. The samples were end coated with a roofing asphalt preparation. A number of additional short lengths of boards remaining from the original material were also dried in this run.

The modified T3-C3 schedule was as follows:

Time	Temperature			Relative humidity	Equilibrium moisture content
	Dry-bulb	Wet-bulb depression	Wet-bulb		
Hr.	°F.	°F.	°F.	Percent	Percent
0 - 24	110	5	105	84	16.2
24 - 48	120	7	113	80	14.1
48 - 72	130	10	120	73	12.1
72 - 96	140	15	125	64	9.6
96 - 120	150	20	130	57	8.0
Equalizing 120 - 151	160	40	120	31	4.3
Conditioning 151 - 167	170	10	160	78	11.3

The hours for the change points were estimated from the drying curves of Runs 1 and 2.

Drying Procedure

In this final run the initial conditions were milder than in the previous runs. Later on an attempt was made to accelerate the drying rate and shorten the drying period. Although kiln samples were weighed regularly, kiln conditions changed after each 24 hours of drying regardless of the calculated moisture content values.

The run started at 9 a.m., June 12, with 110° - 105° F. At the end of each 24-hour period, the wet-bulb temperature was increased 10 degrees and the wet-bulb depression increased stepwise to 7, 10, 15, and 20 degrees.

Intermediate moisture sections were cut after 4 days of drying, when the moisture content of the wettest sample had reached 13.[illegible] percent. After 120 hours of drying, the charge was equalized at 160° - 120° F. for 33-1/2 hours. Final conditioning was then carried out for 15 hours at 170° F. with a wet-bulb depression of [illegible]° F. The total elapsed time, including equalizing and conditioning, was just short of 7 days. This is comparable with the period for Run 2.

The actual drying conditions during this run were as follows:

Kiln-schedule step	Temperature: Dry-bulb	Temperature: Wet-bulb depression	Temperature: Wet-bulb	Moisture content at start of step[1]: Driest sample	Moisture content at start of step[1]: Wettest sample	Elapsed time
	°F.	°F.	°F.	Percent	Percent	Hr.
Drying	110	5.2	104.8	24.0	49.3	0
	115.5	[illegible]	[illegible]	19.5	37.6	[illegible]
	130	10	120	17.6	29.9	48
	140	15	125	13.9	21.1	72
	150	20	130	10.6	14.6	96
Equalizing	160	40	120	7.2	10.2	120
Conditioning	170	10	160	6.0	6.1	[illegible]
End of run				6.7	8.9	167

[1] Recalculated on basis of moisture content values of intermediate sections.

See figure 3 for drying conditions and the drying curves.

Analysis of Run

Immediately before the start of the run, as in the previous tests, a series of moisture sections was cut from each board selected for kiln samples--one from the center and a second from near the end. A third section was cut to provide a wet block from the center area and a dry portion from the end zone. Again, the weighted average of the moisture content values of the dry and wet zones was used to obtain one value, and the highest value of all the sections from each board was used as the

basis for originally calculating ovendry weight of the intermediate kiln samples for use at the start of the kiln runs. Again, the moisture content values of the average sections cut during intermediate determinations were used to calculate back to the actual average initial moisture values. The results are shown in table 8. At the lower moisture content range of the samples in this run, the recalculated values and the arbitrary values agreed very well.

On cutting intermediates, it was found that the moisture content of the average sections ranged from 10.6 to 14.0 percent. On cutting sections into dry and wet or damp zones and light- and dark-colored zones, it was found that at this stage there is no great variation in the moisture distribution. For example, three light-colored zones had a moisture content of 11.7 to 14.1 percent, compared with 12.6 to 14.3 percent for dark-colored zones. In the dry zones the moisture content varied between 12.2 and 13.7 percent, as compared with 13.9 and 16.4 percent for the wet zones. It can be stated, therefore, that the dark streaks in this wood are not always indicative of wetness.

Examination of the material immediately before the start of Run 3 showed that one board had 50 inches of surface checks and another 30 inches. These were still open on the second day. One kiln sample also had slight checks before the start of the run. A few slight surface checks appeared in another board after 3 days of drying. After 6 days, one additional kiln sample showed 13 inches of surface checks, and several fine new checks appeared in additional boards at the completion of the run. The time schedule thus appeared to be slightly too severe.

All the samples were free of collapse and drying stress [illegible] hours after completion of the run. The final moisture content, average and distribution, and casehardening test results are shown in table 9. These showed that, except for the core of one section from sample 15-6, all moisture values were within a range of 1.3 percent and the average of all was between 8 and 9 percent. The one wet core had a few dark streaks in it. The adjacent section could not have had such a high moisture content in its core or it all would have had a higher average moisture content.

Summary of Three Runs

It was found possible to kiln dry previously air-dried virola (*Dialyanthera* s.p.) containing "brown heart" and wet streaks by a variety of low-temperature kiln schedules without collapse. When air-dried stock already contains surface checking, such as this did, mild relative humidity conditions are necessary at the start to avoid extension of the checks. In fact, too severe a relative humidity can open new checks.

Assignment of arbitrarily high moisture content values to samples containing visibly wet areas in the initial moisture sections by taking an unweighted average of the wet zone and the dry zone is a workable device to protect the stock against collapse and honeycombing when used in conjunction with a low-temperature schedule until the average moisture content of the controlling samples is below 25 percent. Intermediate moisture content sections should be cut when this controlling moisture value is about 18 or 19 percent. If all visibly wet zones are gone, the controlling moisture

[illegible] all was between 8 and 9 percent. The one wet core had a few dark streaks in it. The adjacent section could not have had such a high moisture content in its core or it all would have had a higher average moisture content.

[illegible]

It [illegible] to kiln dry previously air-dried virola [illegible] containing "brown heart" and wet streaks by a variety [illegible] conditions are necessary at the start to avoid extension of the checks. [illegible]

Assignment of arbitrarily high moisture content values to samples con- [illegible]

content can safely be assumed to be at the previously determined average moisture content or below. As soon as the intermediate moisture content values are calculated, new ovendry weights for the samples can be calculated and the new moisture content values used to determine the rest of the drying conditions.

The best results, so far as minimum surface checking is concerned, were obtained with Run 2. It is believed that this schedule will give as good results as any. Total drying time in the experimental run was between 6 and 7 days with this schedule, and it is believed that with a schedule of this type, a 7-day drying period could be obtained in a larger commercial kiln.

Very good moisture uniformity was achieved within each of the kiln runs, but there were considerable differences between the average moisture content values of the three runs. Comparative data are shown in table [illegible]. No difficulty was encountered in relieving drying stresses.

Storage of Kiln-Dried Material

Following kiln drying, the long boards from each run were stored in the dry kiln laboratory with temperature and relative humidity close to outdoor winter conditions. This would result in an equilibrium moisture content of about 12 percent. Rapid pickup of moisture by the stock to somewhere near this moisture content may have occurred.

Examination of Dried Stock for Collapse

Five pieces of the kiln-dried material set aside for making a hot-press panel were examined[4] for collapse using a 20-power hand lens. No identification as to kiln runs was made. There was no general collapse. Some slight collapse was present in small zones immediately adjacent to surface checks. Some of the brown-stained cells had very thin walls.

Hot-Pressed Five-Ply Panel Using Kiln-Dried Virola for Core

Two panels were made, the first about 1 month after completion of the kiln drying, using conditions that would simulate factory conditions. The other was made after carefully conditioning the material about 8 months in a 30 percent relative humidity atmosphere. The first panel was very wavy. The second was flat within the limits of normal sanding. Since the former method, including poorly controlled storage of the material after kiln drying and gluing-up after only short conditioned-storage of the components, is about equal to commercial practice, it was concluded that virola lumber with brown streaks is unsuitable for hot-press panel core stock.

Table 1.--Initial moisture content for kiln samples "A" in Run 1

Sample No.	Moisture content of sections: End a	Middle section	Distribution section: Dry zone	Distribution section: Wet zone	Distribution section: Average of dry and wet zones	Kiln sample moisture content value used
	Percent	Percent	Percent	Percent	Percent	Percent
1-A	22.8	23.0	24.1	25.0	24.5	[illegible]
2-A	60.[illegible]	[illegible]	27.0	81.0	54.0	60.0
3-A	33.0	45.[illegible]	26.6	65.0	45.8	45.8
4-A	26.6	[illegible]	32.2	68.7	50.5	50.5
5-A	22.9	32.4	....	32.9	....	32.9
6-A	27.9	44.7	33.5	60.7	47.1	47.1
7-A	43.6	30.4	34.8	65.6	50.2	50.2
8-A	17.4	24.7	25.1	29.8	27.5	27.5
9-A	27.1	24.0	23.8	23.8	23.8	[1]25.5
10-A	29.3	40.4	34.6	72.9	53.8	53.8
Average of 3 wettest	43.5	51.1	34.3	74.2	53.9	54.8
Average of all	31.1	38.2	28.2	52.5	51.2	

[1] Average of middle and end.

Five pieces of [illegible]

Table 1.—Initial [illegible]

Sample No.	Relative content of section				[illegible]
	Percent	Percent	Percent	Percent	
1-A	32.0	23.0	54.1	25.8	[illegible]
3-A	33.0	45.9	26.6	65.0	[illegible]
5-A	33.8	32.4	[illegible]	32.9	[illegible]
8-A	37.3	44.7	53.5	44.7	[illegible]
9-A	37.6	26.7	33.3	33.4	[illegible]
10-A	29.2	48.4	34.8	72.9	[illegible]
Average of					
all	31.1	36.1	26.2	57.5	

[illegible]

Table 7.--Comparative initial moisture content of silo samples in Run 1

Sample No.	Moisture content: arbitrary values	Moisture content: Recalculated values from intermediate moisture content
	Percent	Percent
1-A	25.0	25.7
2-A	60.0	65.0
3-A	45.8	44.5
4-A	50.5	28.4
5-A	32.9	29.0
6-A	47.1	37.7
7-A	[illegible]	44.0
8-A	27.5	22.0
9-A	25.5	27.2
10-A	33.8	39.9
Average of 3 wettest	[illegible]	51.2
Average of all	41.6	38.3

Table 3.--Moisture content of kiln samples "A" during run 1

[illegible]

Sample No.	Moisture content[1]			
	Start of run	Before equalizing	After equalizing	After conditioning
	Percent	Percent	Percent	Percent
1-A	26.5	6.6	5.7	8.3
2-A	53.8	9.7	6.7	8.5
3-A	44.8	8.3	6.2	8.2
4-A	29.8	6.6	5.4	8.4
5-A	39.4	7.2	5.9	8.2
6-A	37.1	7.5	6.2	8.8
7-A	43.8	8.6	5.8	7.8
8-A	23.7	6.7	5.7	8.7
9-A	27.6	6.5	5.4	8.4
10-A	39.0	7.3	6.0	8.5
Average of 3 wettest	50.8	8.9	8.3	8.8
Average of all	36.6	7.5	5.9	8.4

[1] Values based on intermediate moisture content determinations. Values at start of run differ from initial values because of drying or wetting during storage.

Table 4.--Final moisture content and stress test results at end of Run 1

Sample No.	Moisture content			Case-hardening
	Shell	Core	Average	
	Percent	Percent	Percent	
1-A	7.8	7.9	8.2	None
2-A	7.7	8.6	8.5	Do.
3-A	8.8	9.2	8.8	Do.
4-A	7.8	8.7	8.2	Do.
5-A	7.6	8.3	8.5	Do.
6-A	8.3	8.6	8.4	Do.
7-A	8.3	8.9	8.7	Do.
8-A	8.2	8.8	8.5	Do.
9-A	8.1	8.1	8.3	Do.
10-A	8.1	8.8	8.3	Do.
Average of all	8.2	8.6	8.3	
Wettest	8.8	9.2	8.8	
Driest	7.8	7.9	8.2	

Table 7.--Moisture content of sections in Run 2 at the intermediate moisture content determination

Sample No.	Start of run: Based on arbitrary initial values: Average section	Start of run: Dry zone	Start of run: Light-colored zone	Before equalization: Wet zone[1]	After equalization
	Percent	Percent	Percent	Percent	Percent
1-B	[illegible]	15.4	15.3	22.3	[illegible]
2-B	[illegible]	15.6	15.7	[illegible]	[illegible]
3-B	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4-B	17.7	[illegible]	[illegible]	[illegible]	[illegible]
5-B	17.6	15.4	[illegible]	[illegible]	[illegible]
6-B	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7-B	[illegible]	17.[illegible]	[illegible]	[illegible]	[illegible]
8-B	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9-B	15.4	[illegible]	[illegible]	17.[illegible]	[illegible]
10-B	[illegible]	17.9	[illegible]	[illegible]	[illegible]
11-C	[illegible]	17.3	17.[illegible]	[illegible]	[illegible]
12-C	14.5	14.1	14.2	[illegible]	12.3
13-A	[illegible]	14.5	[illegible]	[illegible]	9.2
14-A	[illegible]	14.6	[illegible]	[illegible]	13.7
Average of 3 wettest	21.2	[illegible]	[illegible]	[illegible]	[illegible]
Average of all	18.1	16.6	16.1	22.4	21.5

[1]Where zone was not visibly wet, the zone that felt the dampest or gave best color with an indelible pencil was selected.

Table 6.--Moisture content of kiln samples during Run 2

Sample No.	Moisture content: Start of run: Based on arbitrary initial values	Moisture content: Start of run: Recalculated values[1]	Moisture content: Before conditioning	Moisture content: After conditioning
	Percent	Percent	Percent	Percent
1-B	28.3	28.4	4.5	10.1
2-B	57.9	47.3	7.1	11.6
3-B	45.4	43.9	5.5	10.8
4-B	53.7	49.2	3.3	7.9
5-B	45.8	42.1	5.4	10.3
6-B	50.3	45.4	5.2	9.6
7-B	50.7	46.4	6.2	11.4
8-B	33.4	32.5	8.8	15.4
9-B	26.2	25.7	4.6	10.1
10-B	52.4	46.1	6.0	11.0
Average of 3 wettest	54.6	47.6	7.4	12.8
Average of all	44.4	40.4	5.7	10.8
11-A	(2)	46.6	7.6	13.0
12-C	(2)	21.6	3.6	9.7
13-A	(2)	20.5	5.0	7.7
14-A	(2)	21.5	6.3	9.6
Average of 2 wettest	(2)	34.2	6.9	11.4
Average of last four	(2)	27.6	5.6	9.9

[1]Recalculated on the basis of intermediate moisture content determinations.

[2]No data.

Table 7.--Final moisture content and stress test results at end of Run 2

Sample No.	Moisture content: Shell	Moisture content: Core	Moisture content: Average	Casehardening
	Percent	Percent	Percent	
1-B	9.4	9.5	9.4	None
2-B	9.1	9.4	9.4	Do.
3-B	9.7	9.9	10.0	Do.
4-B	9.6	9.7	9.8	Do.
5-B	9.8	9.6	9.7	Do.
6-B	9.7	10.0	9.6	Do.
7-B	9.5	9.9	9.7	Do.
8-B	9.3	9.6	10.0	Do.
9-B	9.2	10.0	9.3	Do.
10-B	9.2	9.6	9.6	Do.
11-A	9.5	9.8	9.7	Do.
12-C	8.8	9.9	9.9	Do.
13-A	8.5	9.3	9.8	Do.
14-A	8.7	9.0	9.2	Do.
Average of all	9.4	9.7	9.7	
Wettest	9.8	10.0	10.0	
Driest	8.5	9.0	9.2	

Table 8.--Comparative initial moisture content of kiln samples in Run 3

Sample No.	Moisture content: Arbitrary values	Moisture content: Recalculated values from intermediate moisture content
	Percent	Percent
11-B	49.1	49.3
13-B	25.4	24.1
14-B	25.0	24.7
15-B	24.9	26.7
16-B	24.0	24.0
17-B	25.2	25.1
Average of 3 wettest	33.2	33.7

Table 9.--Final moisture content and stress test results at end of Run 3

Table 10.--Comparison of final moisture content values for all three kiln runs

Sample No.	Moisture content: Shell	Moisture content: Core	Moisture content: Average	Casehardening
	Percent	Percent	Percent	
11-B	8.6	8.9	8.8	None
13-B	8.0	8.4	9.1	Do.
14-B	7.9	8.6	8.2	Do.
15-B	7.8	8.7	8.5	Do.
16-B	8.0	10.4	8.8	Do.
17-B	8.3	9.1	9.0	Do.
Average of all	8.0	8.9	8.7	
Wettest	8.3	10.4	9.1	
Driest	7.8	8.0	8.2	

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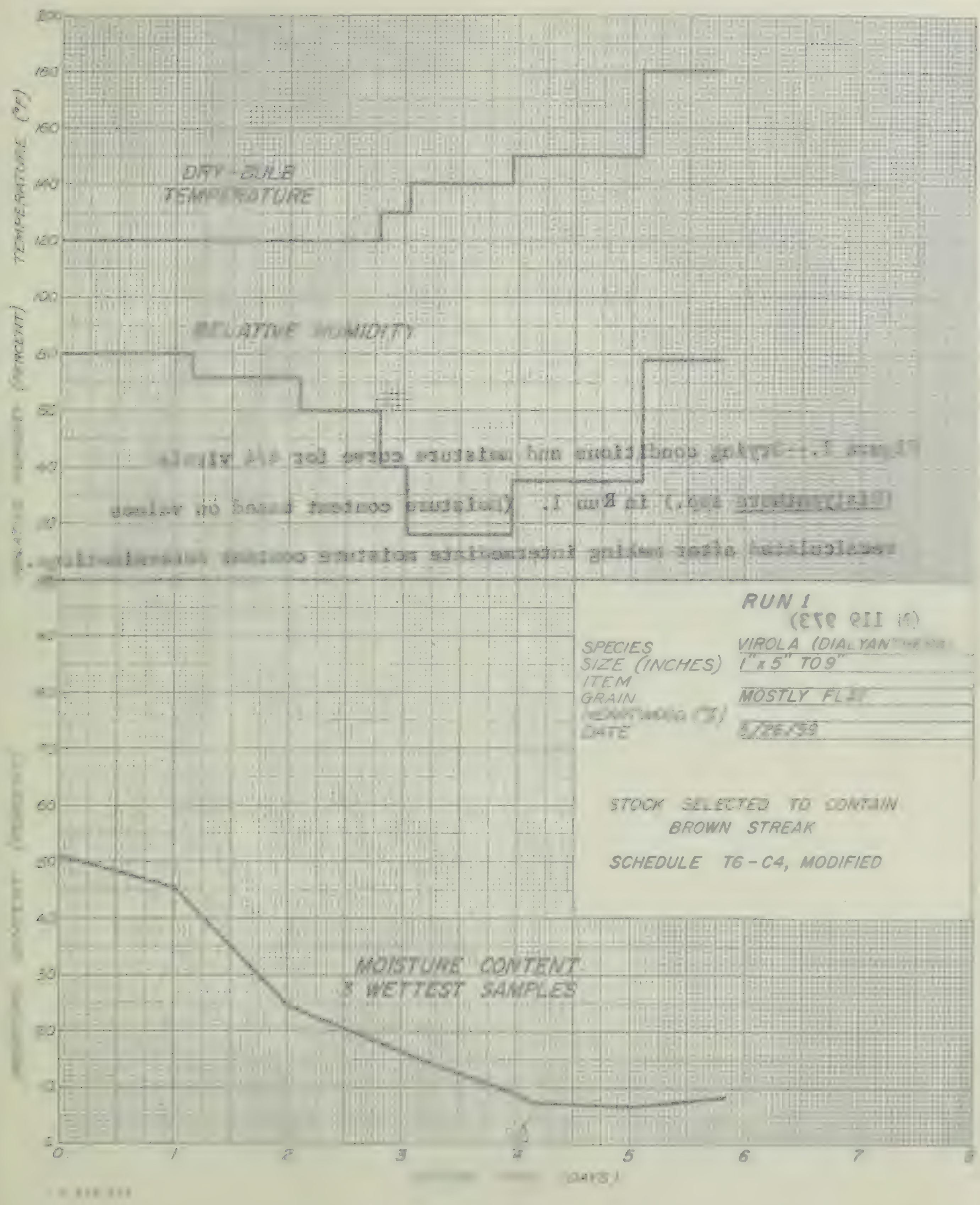
Table 10.--Comparison of final moisture content values for all three kiln runs

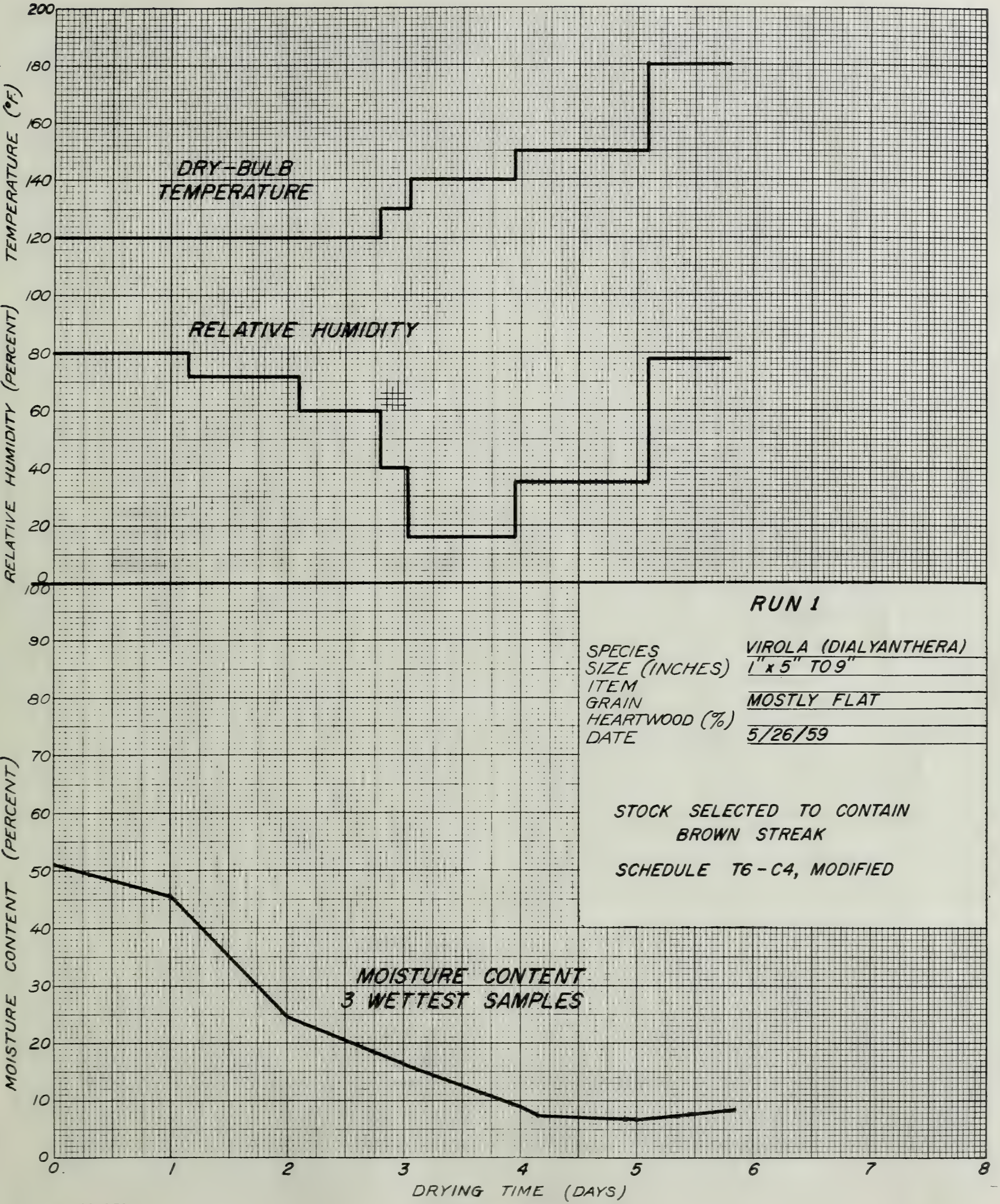
Run No.	Moisture content				
	Average sections				Wettest core
	Average	Minimum	Maximum	Range	
	Percent	Percent	Percent	Percent	Percent
1	8.4	8.2	8.8	0.6	9.2
2	9.7	9.2	10.0	.8	10.0
3	8.7	8.2	9.1	.9	10.4
All	8.9	8.2	10.0	1.8	10.4



DRY-BULB TEMPERATURE
RELATIVE HUMIDITY
TEMPERATURE (°F)
RUN 1
SPECIES VIROLA (DIALYANTHERA)
SIZE (INCHES) 1" x 5" TO 9"
ITEM
GRAIN MOSTLY FLAT
DATE 5/26/59
STOCK SELECTED TO CONTAIN BROWN STREAK
SCHEDULE T6 - C4, MODIFIED
MOISTURE CONTENT
3 WETTEST SAMPLES
(DAYS)

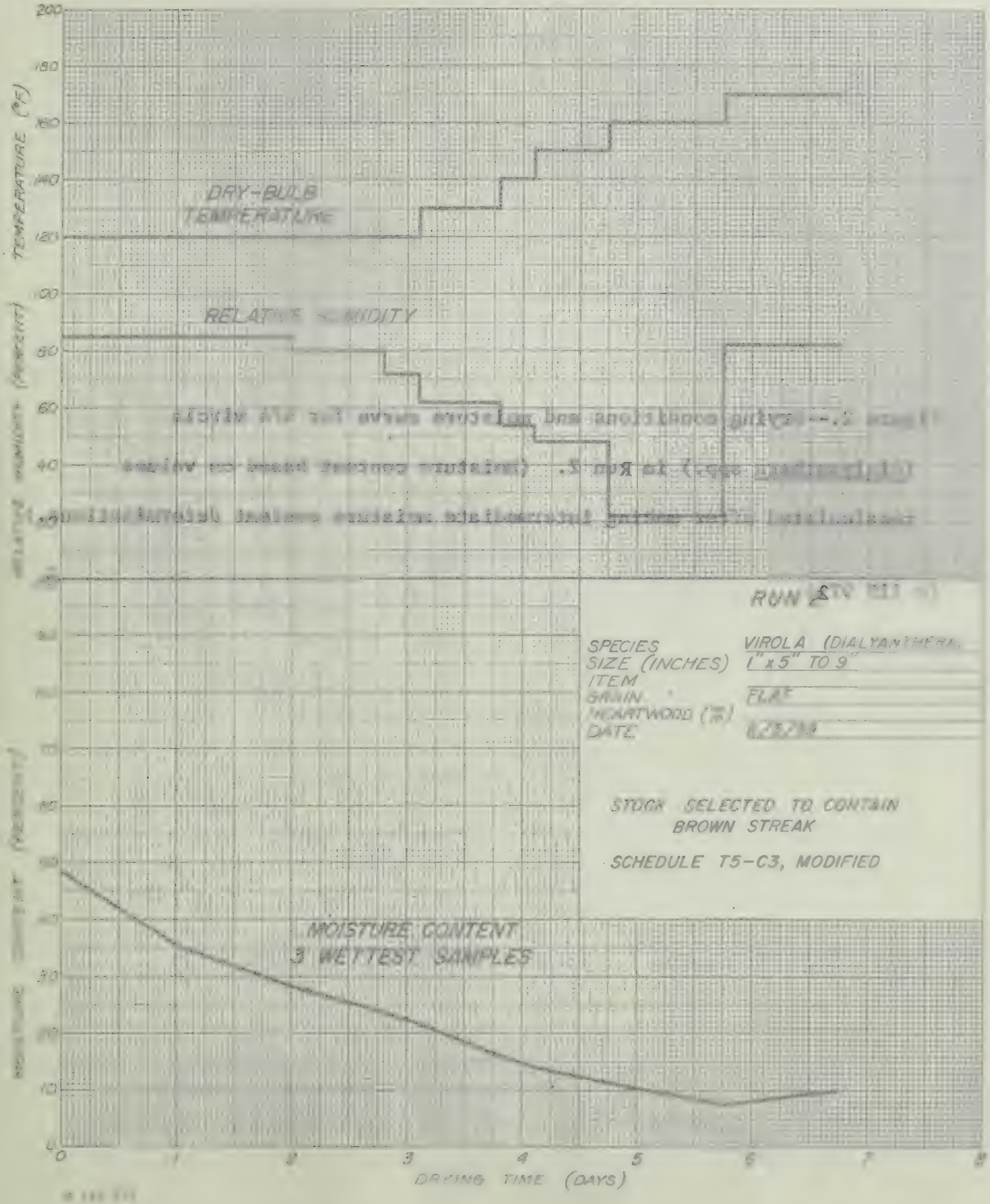
Figure 1.--Drying conditions and moisture curve for 4/4 virola (*Dialyanthera* spp.) in Run 1. (Moisture content based on values recalculated after making intermediate moisture content determinations.)

(M 119 973)



DRY-BULB TEMPERATURE
RELATIVE HUMIDITY
TEMPERATURE (°F.)
RELATIVE HUMIDITY (PERCENT)
RUN 1
SPECIES VIROLA (DIALYANTHERA)
SIZE (INCHES) 1" x 5" TO 9"
ITEM
GRAIN MOSTLY FLAT
HEARTWOOD (%)
DATE 5/26/59
STOCK SELECTED TO CONTAIN BROWN STREAK
SCHEDULE T6 - C4, MODIFIED
MOISTURE CONTENT 3 WETTEST SAMPLES
MOISTURE CONTENT (PERCENT)
DRYING TIME (DAYS)

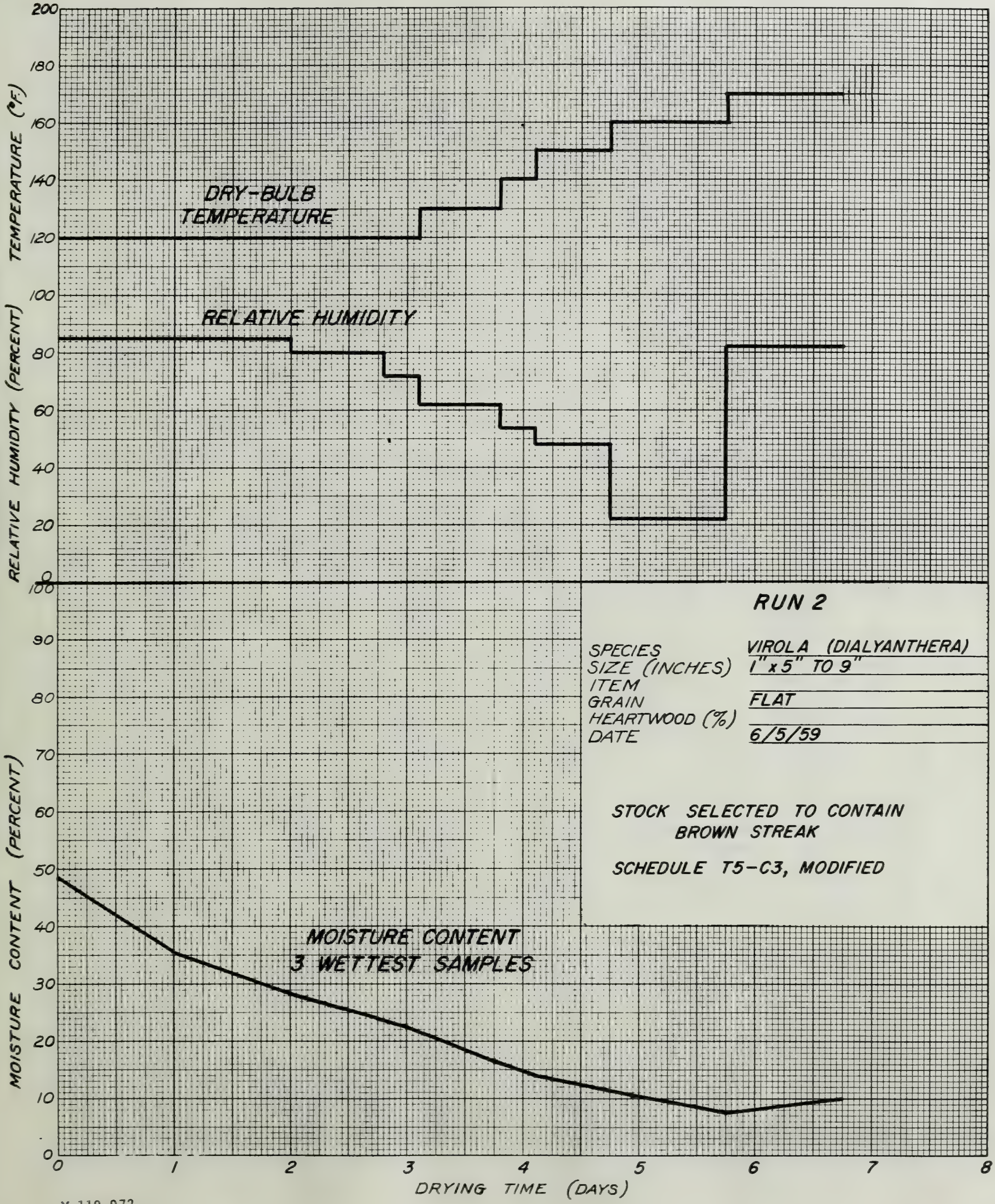
M 119 973



DRY-BULB TEMPERATURE
RELATIVE HUMIDITY
TEMPERATURE (°F)
RELATIVE HUMIDITY (PERCENT)
MOISTURE CONTENT (PERCENT)
RUN 2
SPECIES VIROLA (DIALYANTHERA)
SIZE (INCHES) 1" x 5" TO 9"
ITEM
GRAIN FLAT
HEARTWOOD (%)
DATE
STOCK SELECTED TO CONTAIN BROWN STREAK
SCHEDULE T5-C3, MODIFIED
MOISTURE CONTENT 3 WETTEST SAMPLES
DRYING TIME (DAYS)

Figure 2.--Drying conditions and moisture curve for 4/4 virola (*Dialyanthera* spp.) in Run 2. (Moisture content based on values recalculated after making intermediate moisture content determinations.)

(M 119 972)



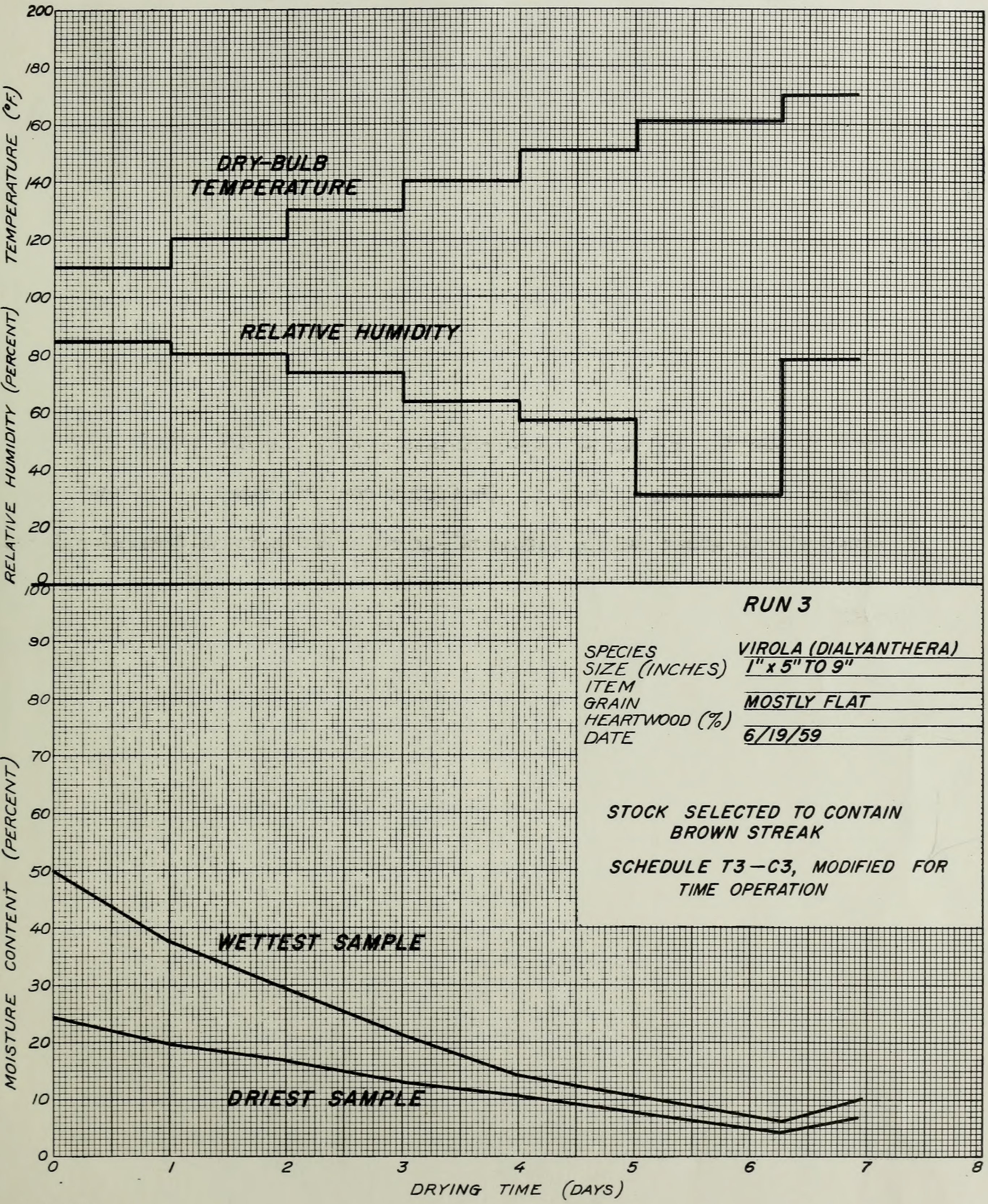
200
180
160
140
120
100
80
60
40
20
0
TEMPERATURE (°F.)
RELATIVE HUMIDITY (PERCENT)
DRY-BULB
TEMPERATURE
RELATIVE HUMIDITY
100
90
80
70
60
50
40
30
20
10
0
MOISTURE CONTENT (PERCENT)
RUN 2
SPECIES VIROLA (DIALYANTHERA)
SIZE (INCHES) 1" x 5" TO 9"
ITEM
GRAIN FLAT
HEARTWOOD (%)
DATE 6/5/59
STOCK SELECTED TO CONTAIN
BROWN STREAK
SCHEDULE T5-C3, MODIFIED
MOISTURE CONTENT
3 WETTEST SAMPLES
0
1
2
3
4
5
6
7
8
DRYING TIME (DAYS)

M 119 972

RUN 3
SPECIES
SIZE (INCHES) 1" x 5" TO 9"
ITEM
GRAIN MOSTLY FLAT
HEARTWOOD (%)
DATE
STOCK SELECTED TO CONTAIN BROWN STREAK
SCHEDULE T3—C3, MODIFIED FOR TIME OPERATION
WETTEST SAMPLE
RELATIVE HUMIDITY (PERCENT)
TEMPERATURE (°F)
DRYING TIME (DAYS)

Figure 3.--Drying conditions and moisture curves for 4/4 virola (*Dialyanthera* spp.) in Run 3. (Moisture content based on values recalculated after making intermediate moisture content determinations.)

(M 119 971)


DRY-BULB TEMPERATURE
RELATIVE HUMIDITY
TEMPERATURE (°F.)
RELATIVE HUMIDITY (PERCENT)
RUN 3
SPECIES VIROLA (DIALYANTHERA)
SIZE (INCHES) 1" x 5" TO 9"
ITEM
GRAIN MOSTLY FLAT
HEARTWOOD (%)
DATE 6/19/59
STOCK SELECTED TO CONTAIN BROWN STREAK
SCHEDULE T3—C3, MODIFIED FOR TIME OPERATION
WETTEST SAMPLE
DRIEST SAMPLE
MOISTURE CONTENT (PERCENT)
DRYING TIME (DAYS)
200
180
160
140
120
100
80
60
40
20
0
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8

M 119 971

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